Report on the Review of the LARP/CERN LHC Tune PLL Feedback Program 4/11/05

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The Collaboration between LARP and CERN has demonstrated prototype hardware and system architecture that has the potential to satisfy the LHC tune tracker/feedback system requirements. Team members have established the rapport that enables a successful collaboration.

Technical specifications for the Tune Feedback (TF) system of the LHC are listed in LHC-B-ES-0004, entitled "On the Measurement of the Tunes, Coupling, and Detuning with Momentum and Amplitude in LHC". These specifications, and the LARP Tune Feedback planning to fulfil them, address both the basic diagnostic ability to measure tunes, chromaticities, and coupling, and also the significantly harder task of "closing the loop" to feedback on these quantities.

1. Can the resource loaded action plan for the Tune Feedback LARP task for 2005-2008 be validated? Are sufficient resources (manpower and money) committed to insure that the schedule can be met?

Peter Cameron is the lead BNL resource for the project and currently works on the PLL tune system half time. He delivered 7 of the 12 presentations at this review. This project is perceived as high profile/priority and considered an important method of tune measurement for LHC at injection and monitoring beam up the ramp. Brookhaven National Lab as the main LARP collaborator needs to add some manpower depth to the project, preferably accelerator physics support and engineering modeling of the feedback systems. The current plan relies too heavily on one individual.

A list of resources and schedule milestones was presented, but not in a unified format. Details of responsibilities between BNL and CERN, individual participants and their time commitment, plus costs for prototyping M&S, all need to be formulated in an organized document.

CERN insists that the system architecture and implementation must comply with LHC standards. Consequently, CERN provides the majority of the hardware, which partially relieves LARP of the hard installation deadlines. LARP, however, is on the critical path for the bulk of the associated low-level programming (gate array, FEC, and the development of higher-level feedback software).

Contingency, backup plans and schedules need to be developed in the event RHIC is not available for doing the important preliminary testing. (See item 4 below.)

Travel expenses will be necessary to successfully complete the project. Historically, when budgets are tight travel is one of the first items to be cut. The budget must protect these funds for a successful collaboration.

2. Will the current design meet the technical specifications for

a) Tune,

b) Coupling, and

c) Chromaticity measurement and control?

Are the requirements sufficiently precise and detailed?

Preliminary testing at RHIC has shown that the PLL method can track tunes and so should be invaluable for the LHC. However, while the PLL has been available for a few years at RHIC it has not been robust enough to be used in a routine way for tune feedback, let alone for chromaticity or coupling feedbacks. The LHC commissioning plan suggests that tune tracking will be required as soon as possible after initial commissioning. Tune feedback is thought not to be essential during initial commissioning, but could well be required during the following phases. To enable these requirements at LHC, a fully operational system at RHIC should be implemented first.

The tracker is potentially confused by jumping to nearby lines of other plane tune (when coupled), to the synchro-betatron side bands (if chromaticity is large), and perhaps from the forest of power-line harmonics that have been observed on the beam at RHIC (and at the Tevatron). The proposed coupling compensation, using measurements of the cross-excitation, and feeding back on the result, is very clever, but has even less testing and experience. As for the power-line harmonics, it is not proven that a PLL can truly lock on a line that is not excited by the loop.

However, an intelligent, adaptive loop may be able to avoid both traps, by noting what changes when the loop attempts a correction. If, for example, it is fixed on a 60 (or 50) Hz harmonic, then a tune change will not move the peak, and similarly, if fixed on the wrong tune eigenmode, then attempting a tune correction will not change the measured mode. The loop would then seek the correct line and relock. Such an algorithm could improve reliability, but would need elaboration and testing.

The direct-diode-detection method (called either "3D" or "BBQ", for baseband Q) appears to be a big advantage for the PLL. Its high dynamic range and common-mode suppression provides a vast improvement over previous attempts to track tunes by mixing down high frequencies. This detection method will respond to other transverse motions like head-tail or quadrupole, which may provide even more information about the beam (at the cost of providing some additional lines that may further complicate the PLL's locking). It also eliminates the need for mechanical motion of the pickup for centering.

3. Do the specifications adequately address the evolution of requirements from initial low-intensity beam commissioning to high luminosity operations?

Requirements on the tune, chromaticity and coupling measurements with the instrumentation discussed here are well defined by the CERN-LARP collaboration. However, details of system testing and modeling before final beam tests need definition.

Will there be any opportunities to measure the PLL system with beams of 1e9 protons at RHIC (close to the pilot-bunch current in LHC)? It would be good to have measured the system's dynamic range prior to installation in the LHC.

Operating all of the multiple nested feedback loops—for tune, coupling, chromaticity, orbit, transverse damper, and low-level RF—cannot be successful unless careful

provisions are made to avoid crosstalk. For example, the tune loop may undo the modulation introduced to measure chromaticity, and the orbit loop may try to correct locally the change in ring radius resulting from the RF frequency change needed for chromaticity measurement. The loops might be sequential (at the cost of slowing the overall correction rate), or a slower loop might measure only at the zero crossing of a faster one, or the loops might include code to avoid undoing changes caused by all the others (by having the orbit loop, for example, take the frequency offset into account).

4. Does the schedule insure a high probability that a working tune feedback system will be available when energy ramping is first attempted? Will tune feedback be needed?

The list of action items from the March 2005 workshop at BNL mentioned several times the urgency of performing certain tests in RHIC. However, at the present review it was stated that RHIC management has decreased interest in developing tune feedback for RHIC. This lack of priority at BNL could seriously impede the testing of the PLL in tune feedback mode.

The current run of RHIC ends in June, and it was stated that the next version of the PLL system would not be ready before that date. RHIC's operation schedule for next year has been truncated to 11 weeks. There are rumours of combining two years of running, hence skipping the entire 2006 run at RHIC. This has serious implications for supporting this LARP project.

The SPS may provide an alternative testing venue once it turns on in May 2006. A contingency plan, including resources necessary to provide a prototype PLL system, should be developed if RHIC's availability is limited.

5. Are the control system interfaces sufficiently well defined?

When the system is brought to the LHC, the user interface must switch from Labview (used at RHIC) to CERN's FESA (Front-End System Architecture). At the same time, the front-end computers and crate processors must be changed. The experiences of the review-committee members suggest that these changes may cause more conversion headaches than presently anticipated.

Software and control-system integration is an area where significant effort beyond the presented estimate may be necessary. LARP management needs to have a contingency budget to cover this expense or a plan to shift this responsibility to CERN. The system will only have value if all the details of the interface are successfully implemented.

Full testing of the controls interface at RHIC is encouraged. Experience with system integration at other laboratories has met with limited success and requires significant effort. Operational limit testing, error handling, and detailed feedback strategy in case of lost lock etc. should be established.

Very close collaboration between CERN and BNL controls interface experts needs to begin immediately. This is especially true if a prototype system will be tested in the SPS in the latter part of 2006.

Remote access to instrumentation must be encouraged. Such access could be invaluable in a collaboration that spans continents by maintaining involvement and providing for support beyond the initial commissioning stage.

An interface should be added to acquire the raw BBQ waveform data with time stamping so that it could be correlated with results obtained by the PLL tune system.

The LARP/CERN collaboration should plan to develop a common library of software tools for the development of the FPGA code.

6. Is the beam-commissioning plan adequate for this stage of the project? Will sufficient resources (primarily manpower) be in place?

Scheduling three months to commission both LHC beams to full energy is very optimistic and success oriented. What contingency is built into the plan? How does this affect the LARP collaborators that will participate in the commissioning process?

The PLL system is not intended to be operational on the first day of commissioning. It is anticipated that parasitic studies will be allowed for the first months of commissioning. CERN is planning on having at least 3-4 independent means of measuring tune. The PLL tune measurement system is preferred for injection and ramping.

Dedicated commissioning time for PLL tune measurement and feedback during the LHC commissioning period should be foreseen.

Resources for commissioning at CERN now include Peter Cameron, plus additional resources that have not been identified. At this preliminary stage, it is a good start. But with the commissioning of a prototype at both RHIC and SPS expected to take place within the next 18 months, more planning is necessary.

7. What are the action items (not listed in order of priority)?

BNL management should be petitioned to allow the requested testing of the PLL tune system in RHIC. The LARP BNL collaborators should develop a plan that includes the BNL resources to support this request.

The 60 (50) Hz "problem" needs to be clearly defined as a problem by measurements in RHIC. The expected magnitude of the 50 Hz effect at CERN should be established as far as possible. If the PLL cannot track the tune through the 60-Hz lines, the system will not work in a feedback loop. If so, it may take some effort to mitigate and should be done well before delivery to CERN. Can increased beam excitation be implemented to improve the S/N while going through the resonance? Alternatively, the committee recommends using the direct BBQ signal for adaptive control of the PLL. This requires some sort of pattern recognition that appears challenging but probably workable in higher-level software. It is highly desirable to have an accurate mathematical model of the BBQ to achieve better understanding of the 60-Hz problem in particular and, more generally, the of the implications of this nonlinear detection on mixing of different harmonics of beam motion. Integration of adaptive software for tune correction with other tune measurement techniques would be useful.

A detailed commissioning plan for the PLL tune tracking/feedback system was not presented. Such a plan should be created for the next prototype, the system to be installed at the SPS, and the final LHC system. This will require close collaboration between LARP and CERN.

Plans for avoiding battles among the feedback loops must be worked out and tested well before feedback is needed for LHC.

Past experience at many accelerator facilities has shown the need for several iterations of hardware/software modifications during the commissioning period. Unanticipated problems may show up during commissioning and operation. The initial system installed at LHC must have sufficient flexibility to adapt rapidly for continued commissioning success. This type of design requires significant effort in the design stage.